Breakdown of Diffusion in Wave Propagation in Random Media

A. Z. Genack, Queens College of CUNY, DMR-0205186

Though all objects have both a wave and a particle nature, one or the other aspect often catches the essence of a physical problem. We find in measurements of the propagation of pulsed microwave radiation, that if one waits long enough, the wave characteristics of randomly diffusing particles becomes apparent. The rate of particle or photon diffusion slows down while the degree of correlation of the photon number or intensity increases with time delay, even though the degree of correlation of the wave or field does not change. These effects arise because of overlaps of waves inside of the medium which may trap either photons or electrons.

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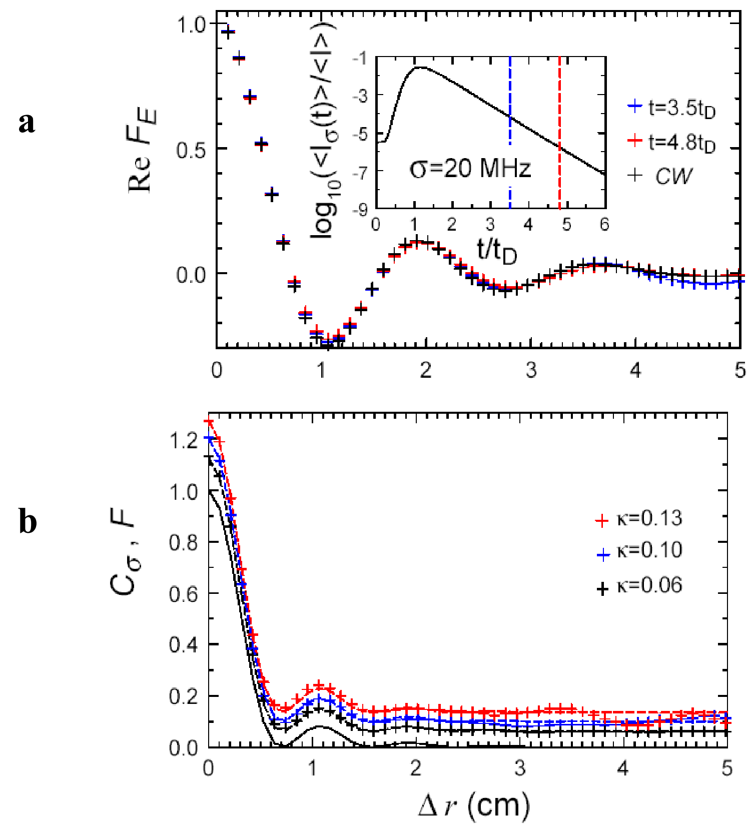

As the time delay from an exciting pulse of microwave radiation increase, (a) the spatial variation of correlation in the field does not change, whereas, (b) the correlation of intensity increases.

Previous measurements have found that the intensity of light in random samples decays at a constant rate after the wave has penetrated into the sample. This is explained in a model that treats the average propagation of electromagnetic radiation in samples which scatter the wave many times over using the same model that describes the diffusion of particles such as gas molecules or electrons, which are subject to random collisions. We find, however, that the decay rate for energy slows down in time. We show this is associated with the trapping of the wave inside the sample. This can be understood from two points of view. (1) The wave excites a collection of modes of the wave inside the sample and at long times only the longest lived of these modes survive. These modes would tend to have their energy peaked in the center of the sample far from the sample boundary at which energy might leak out of the sample. (2) The waves cross within the sample and add in such a way to suppress escape from the sample. This is the same process that leads to the localization within the sample of electrons or other particles. As the decay rate of photons from the sample is suppressed, the degree of correlation in intensity or photon number is greatly enhanced with the passage of time.

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Education:

One undergraduates (Gabby Krauss) and two graduate students (Andrey Chabanov and Bing Hu) contributed to this work. Gabby Krauss is going on to study engineering at Cooper Union, Andrey Chabanov has gone on to a post doctoral position at the Department of Materials Science at the University of Minnesota, and Bing Hu is still a student in our group.

Societal Impact:

This work has revealed that the fundamental parameter of wave propagation is the degree of intensity or photon correlation, which increases dramatically with time delay. Since wave-particle duality is fundamental to transport this will lead to improved understanding of electron transport in nanostructures and to photon propagation when systems are not perfectly ordered.